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# Gallium Arsenide Welded Panel Technology for Advanced Spaceflight Applications

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## Abstract

A significant impediment to the widespread use of GaAs solar cells in space is the cost and weight of the GaAs substrate. In order to overcome these problems, Spectrolab is pursuing thin cell technologies encompassing both LPE GaAs on GaAs and MOCVD GaAs on Ge cells.

In this paper we describe Spectrolab's experience in the manufacture of 4-6 mil 2 cm x 4 cm GaAs cells on our LPE production line. By thinning the cells at a late stage of processing, production yields comparable to 12 mil cells have been achieved. Data are presented showing that GaAs cells can be welded without degradation and have achieved minimum average efficiencies of 18% AM0, 28°C with efficiencies up to 20%.

Spectrolab, in conjunction with Spire Corporation has also been pursuing GaAs on Ge cell technology in support of larger area lighter weight power systems. Data are presented showing that individual 2 cm x 2 cm, 8 mil cell efficiencies up to 21.7% have been achieved. Efficiencies up to 24% AM0 will be possible by optimizing the GaAs/Ge interface. Cells have been welded without degradation using silver interconnects and have been laid down on an aluminum honeycomb/graphite facesheet substrate to produce a small coupon. The efficiency was 18.1% at AM0, 28°C.

## Thin 2 cm × 4 cm GaAs Cells

Spectrolab's 12 mil LPE GaAs manufacturing process has been modified to accommodate processing of 5 mil GaAs cells at high yield. The cross sectional cell construction which has been described in detail elsewhere [Ref. 1] is shown in Figure 1. The cell also utilizes the Hybrid Etch-Through (HET) front contact structure (shown in Figure 2) to allow assembly by welding or soldering without degradation [Ref. 2].

Initially substrates were etched from 12 mil to 5 mil prior to LPE growth and subsequently processed at that thickness. However, significant component losses due to breakage at all stages of processing led us to investigate an alternate route to cell thinning.

In Figure 3 we show the baseline process, modified to include thinning after frontside processing. Thinning at this late stage of processing resulted in only marginal losses during back contact metallization, sintering, dicing and test.

In Figures 4, 5, 6 and 7 we show the distribution of $V_{oc}$, $I_{sc}$, FF and efficiency for over 100 thin cells recently produced. High open circuit voltages with a tight distribution in FF and efficiency are achieved by statistical control of all growth parameters and front contact sintering conditions. The latter has been found to be particularly important in controlling $V_{oc}$ and FF since over sintering of structures with thin radiation hard emitters can significantly increase the second diode saturation current $I_{o2}$. The average efficiency of bare cells shown in Figure 7 is 17.7%. It should be noted that a coverglass gain of approximately 2-3% is observed when CMX or fused silica covers are attached using DC93-500 adhesive resulting in average efficiencies of approximately 18% AM0 28°C.

Spectrolab has parallel gap welded solid silver interconnects to both the front and back of 5 mil GaAs cells without any electrical degradation being observed. However, some cracking during backside welding of glassed cells has been experienced. Similar problems have also been observed on 12 mil cells. Breakage is largely independent of weld tip pressure which implies that the cracking is induced by thermal stress rather than by tip pressure alone. This problem is currently being addressed.

During April 1988 a coupon of fifty 5 mil GaAs cells on an aluminum honeycomb substrate with graphite facesheets will be assembled using welded silver interconnects. Based on measured efficiencies of cells already fabricated for this project it is expected that the coupon efficiency will be greater than 18% AM0.

### 8 Mil GaAs/Ge Cells

In order to address issues relating to the cost, size and weight limitations of GaAs cells [Ref. 3] Spectrolab, in conjunction with Spire Corporation has been developing GaAs on Ge solar cells. These cells offer substantial increase in power due to the bandgap matching between GaAs and Ge which allows two terminal monolithic dual junction cells to be fabricated.

It is believed that 3 mil thick cells up to 7 cm x 7 cm or even 8 cm $\times$ 8 cm can ultimately be achieved due to the excellent mechanical properties of Ge substrates.

In Figure 8 we show the computed internal spectral response of a GaAs/Ge cell in which the Ge substrate is active. The parameters used for modeling both the GaAs and Ge cells are shown in Table 1. Due to the low bandgap of Ge (0.67 eV) the cell response extends out to 1.87 microns wavelength. Provided the back surface recombination velocity at the back of the Ge substrate can be kept below 100 cm $sec^{-1}$ the current in the Ge base is approximately 30 mA $cm^{-2}$ and a current matched cell is produced. In Figure 9 we show the projected AM0 I-V characteristic of such a cell. We estimate that a 24.4% efficiency cell is achievable with approximately 5.5% being contributed from the Ge cell.

In Figure 10 we show the illuminated AM0 I-V characteristic of a 2 cm $\times$ 2 cm 8 mil GaAs/Ge cell fabricated by Spire Corporation and measured at NASA LeRC. An AM0 25°C efficiency of 21.7% was achieved. It is believed that the present efficiency is limited by a recombination velocity of approximately $10^6$ cm $sec^{-1}$ there. Reduction in these states by optimization of the growth conditions should allow efficiencies up to 24% to be achieved.

We have also demonstrated the assembly hardness of GaAs/Ge cells by fabricating and testing a small 3 cell welded coupon. The substrate material was 0.75 inch aluminum honeycomb with graphite facesheets. The cells were filtered using 6 mil CMX coverglass and DC93-500 adhesive. A glassing loss of approximately 2% was observed. Cells were interconnected by parallel gap welding using solid silver interconnects. No electrical degradation was observed after welding. Pull tests on other sample cells indicated excellent pull strengths of over 3 newtons on both sides of the cell. In Figure 11 we show the AM0, 28°C characteristic of the coupon. An overall efficiency of 18.1% was achieved. The small amount of shunting seen in the characteristic was attributed to leakage paths at the GaAs/Ge interface rather than to welding assembly degradation which was not observed on any cells.

## Conclusion

Thin 5 mil 2 cm × 4 cm GaAs solar cells have been fabricated by a high yield process. The cells had an average efficiency (bare) of 17.7% with a projected average efficiency after glassing of 18%.

GaAs/Ge cells up to 21.7% efficiency were also fabricated and have been shown to be easily assembled by welding into an 18.1% efficiency coupon. Pull strengths of the front and back contact metallizations were excellent and exceeded 3 newtons. These cells show promise of achieving efficiencies of up to 24% AM0 in 7 cm × 7 cm or 8 cm × 8 cm form for future high power, radiation hard missions.


## Acknowledgements

The authors wish to thank Russell Hart of NASA Lewis Research Center for making AM0 cell measurements on GaAs/Ge cells.


## References


[ 1] M. Gillanders, B. Cavicchi, D. Lillington and N. Mardesich, *Proc 19th IEEE PVSC*, New Orleans, p289 (1987).

[ 2] B.T. Cavicchi, H.G. Dill and D.K. Zemmrich, *Proc 19th IEEE PVSC*, New Orleans, p67 (1987).

[ 3] K.I. Chang, Y.C. Yeh, P. Iles, J. Tracy and R.K. Morris, *Proc 19th IEEE PVSC*, New Orleans, p273 (1987).

| LAYER | THICKNESS (uM) | DIFF.L (uM) | DIFF.CFT. ($cm^2/s$) | SURFACE REC. VELOCITY (cm/s) | DOPING CONC. ($1/cm^3$) | DAMAGE CFT. (1/e) |
|---|---|---|---|---|---|---|
| TOP CELL : AlGaAs Windowed GaAs Cell | | | | | | |
| Window | .1 | .2 | .27 | 1E6 | 2E18 | -- |
| Emitter | .5 | 5 | 90 | 1E4 | 2E18 | 3.5E-8 |
| Base | 5 | 2 | 5 | 1E2 | 2E17 | 1.8E-7 |
| BOTTOM CELL : Ge | | | | | | |
| Emitter | .1 | 50 | 24 | 5E3 | 1E19 | 1E-10 |
| Base | 75 | 200 | 15 | 1E2 | 4E17 | 1E-10 |

Table 1 Parameters Used in Cell Modeling

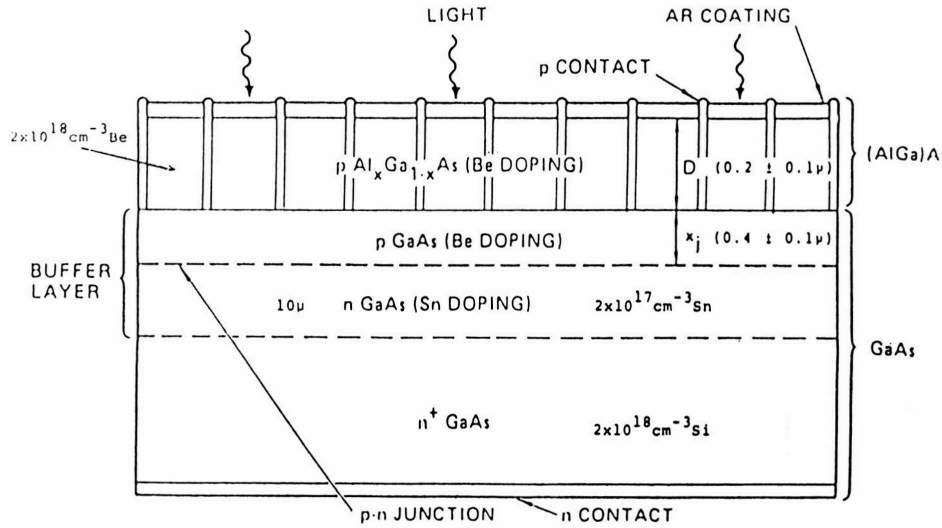


Fig 1 GaAs Cell Cross-Section

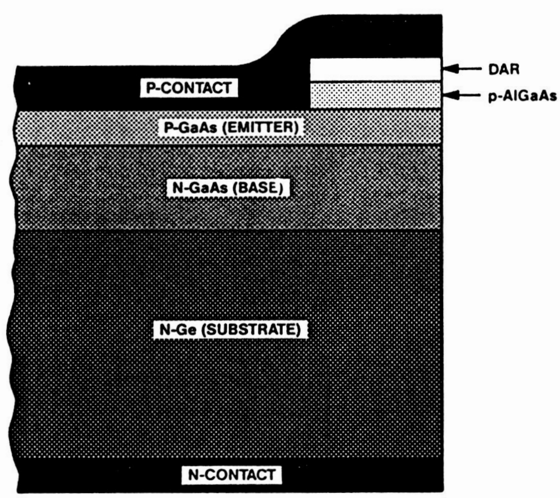


Fig 2 Hybrid Etchthrough Contact

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BLACK AND WHITE PHOTOGRAPH

ETCH

BUFFER/BASE GROWTH

WINDOW GROWTH

ANNEAL

DAR COAT

PHOTOLITHOGRAPHY

ETCH

FRONT CONTACT METALLIZATION

LIFT-OFF

FRONT MASK

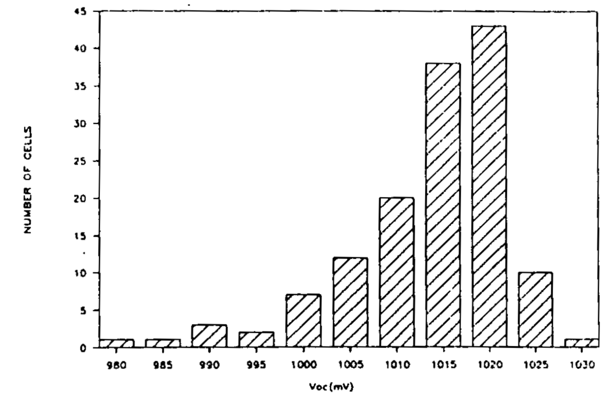
ETCH TO 5 MILS

BACK CONTACT METALLIZATION

SINTER

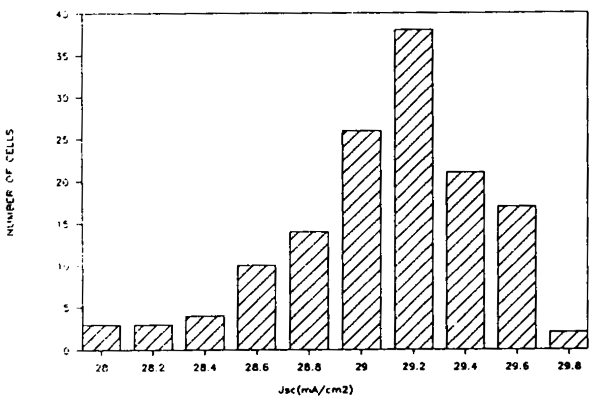
DICE

Fig 3 Thin Cell Process Sequence



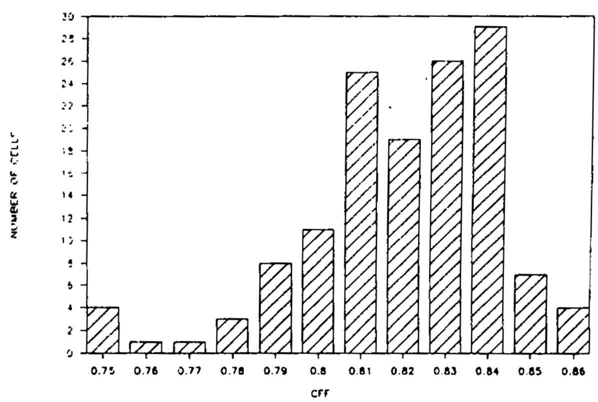

HISTOGRAM OF Voc FOR 163 4-6mil GaAs CELLS (1011mV AVE.)

Fig 4 5 mil GaAs Cell $V_{oc}$ Distribution



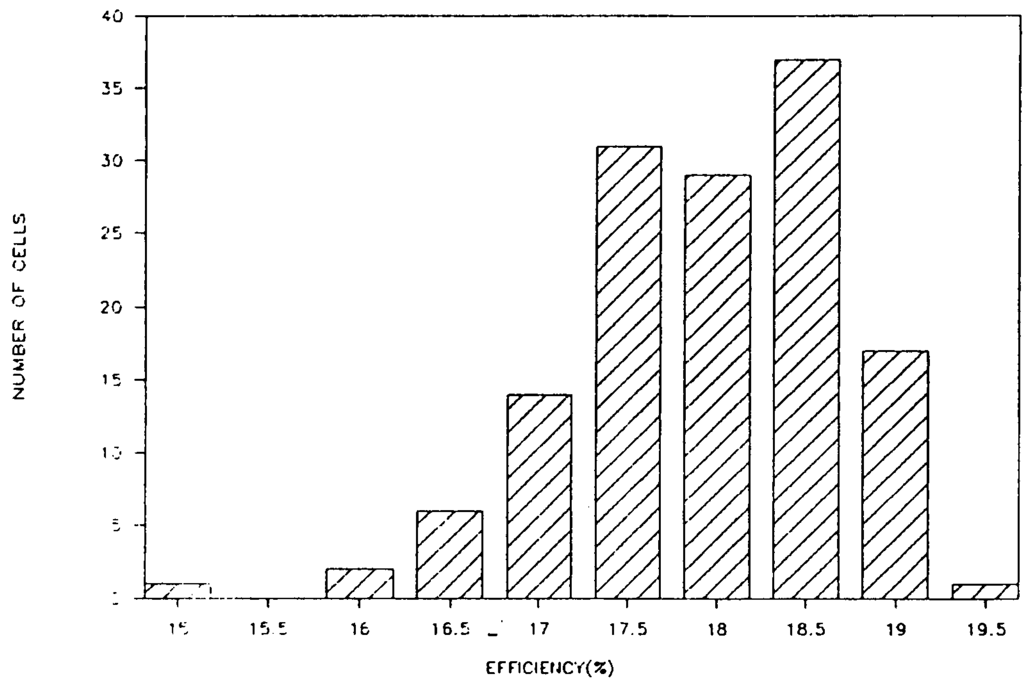

HISTOGRAM OF Jsc FOR 163 4-6mil GaAs CELLS (29.1mA/cm$^2$ AVE.)

Fig 5 5 mil GaAs Cell $J_{sc}$ Distribution




HISTOGRAM OF CFF FOR 163 4-6mil GaAs CELLS (.813 AVE.)

Fig 6 5 mil GaAs Cell CFF Distribution




HISTOGRAM OF EFFICIENCY FOR 163
4-6mil GaAs CELLS (17.7% AVE.)

Fig 7  5 mil GaAs Cell Efficiency Distribution

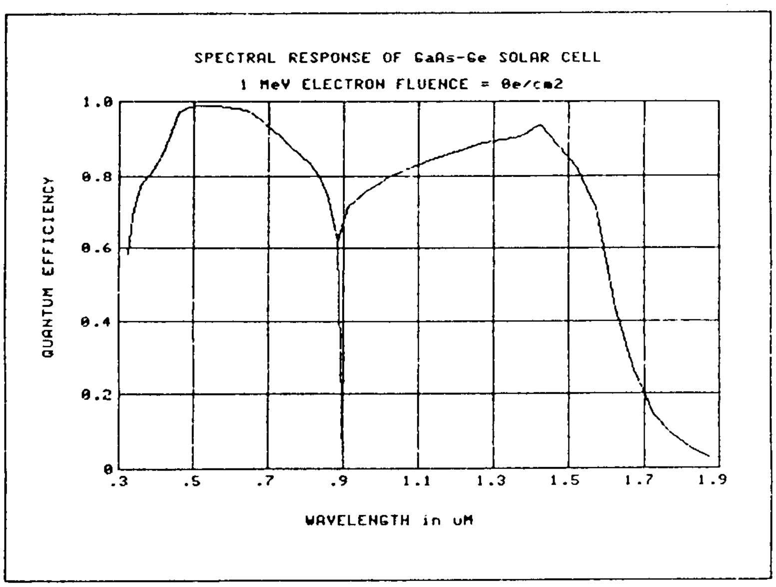



Fig 8  GaAs/Ge Cell Internal Q.E.

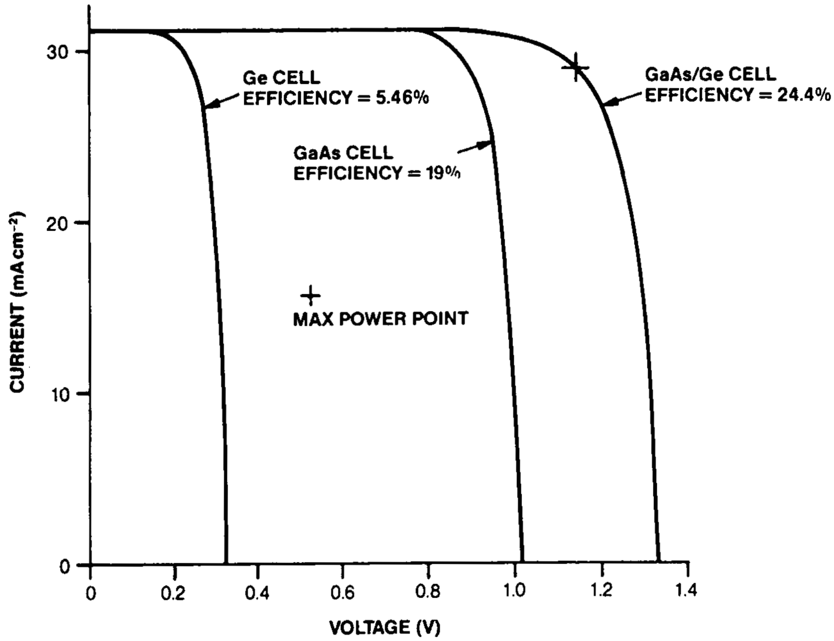



Fig 9 Predicted GaAs/Ge Cell Performance

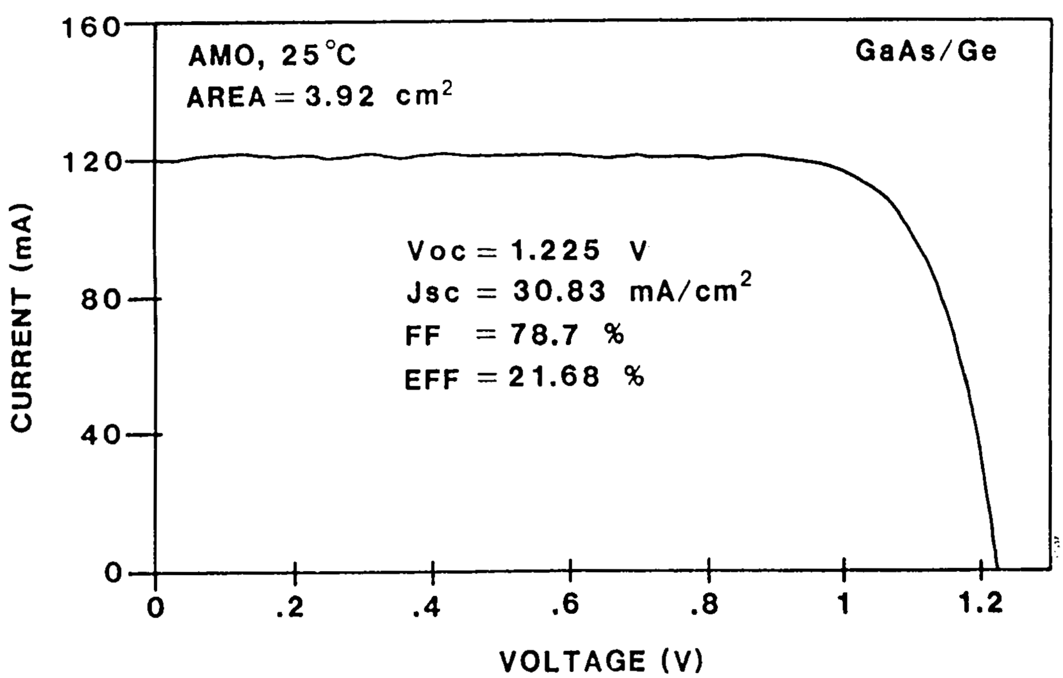



Fig 10 Measured I-V curve of 2 cm x 2 cm GaAs/Ge Cell

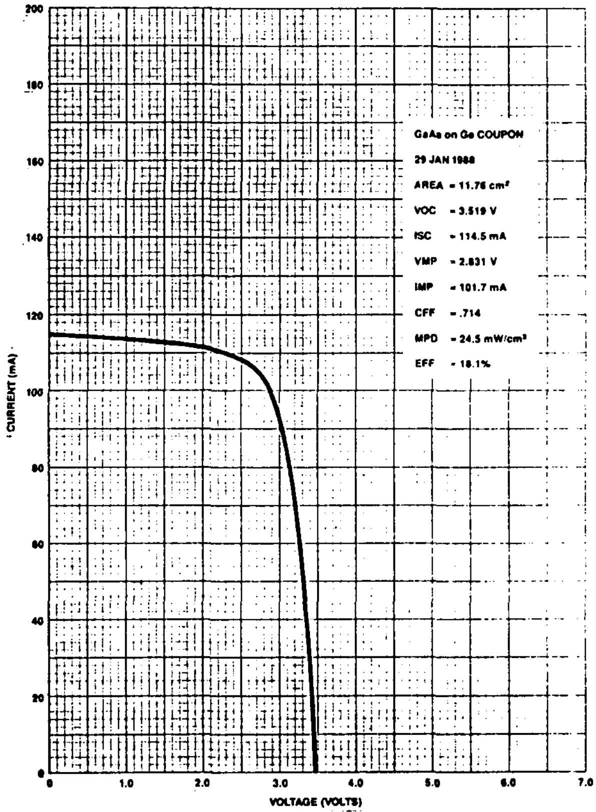



Fig 11  Measured I-V Curve of GaAs/Ge Coupon

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